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A Treatise on Non-Darcy Flow Correlations in Porous Media

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Abstract

Non-Darcy Flow behavior is important for describing fluid flow in consolidated or unconsolidated porous media when abrupt changes in velocity dominates. A criterion or a generalized equation is required to understand this flow behavior in the isotropic/anisotropic carbonate & sandstone reservoirs, and naturally or hydraulically fractured reservoirs. Various correlations and equations have been reviewed in this paper to quantify this non-Darcy coefficient (i.e., beta coefficient) mathematically. It has been observed that this coefficient is highly dependent on rock properties (mainly porosity, permeability and tortuosity). An algorithm to determine the values of the beta coefficient by using the correlations have been presented & coded and converted in to a robust user-friendly simulator. This simulator can take a large amount of data set as *input* and will generate a large data set of beta values as *output*. The obtained or calculated beta value is very useful for predicting the change in pressure gradient with respect to velocity and hence can give the best estimate of hydrocarbon production under challenging or adverse pressure drop conditions.

Keywords: Non-Darcy flow; Viscous flow; Beta coefficient; Simulator; Rock properties

Introduction

The relationship between the pressure drop and flow rate in problems of fluid flow through porous media is known to be affected by the nature of flow through the porous matrix. It has been observed by Darcy that the pressure drop remains proportional to the rate of flow at low Reynolds Number 1. But at high flow rate, flow will exhibit non –linearity with respect to velocity which make Darcy's Law inapplicable at these conditions. To account this non-linear relationship in between pressure gradient and velocity, to turbulence, a non-Darcy term was introduced. When the fluid particles enter in to the porous (consolidated and unconsolidated formations), they are subjected to acceleration and deceleration process depending on the flow rate conditions. In the laminar flow, there is a continuous reversible interchange of kinetic and pressure energy as the acceleration and deceleration process continues. But, in turbulent conditions or high flow rate conditions, the interchange includes significant irreversibility due to the extra fluid motion above that occurring in laminar flow 2. This extra fluid motion is caused by the inertial effects in the deceleration process. The phenomenon is referred as Non-Darcy flow and was first introduced and investigated by Forcheimer 3. Different terminology and names have been proposed by various investigators for the Forchheimer's Non-Darcy coefficient. It has been named as Turbulent Factor, Characteristic Constant of Porous Medium, and Coefficient of inertial resistance, Velocity coefficient, Coefficient of Inertial Resistance, non-Darcy coefficient and the Beta Factor. Tablerepresents the different nomenclature of Non-Darcy term and its applicability in porous media.

Numerous attempts haven been made by Cornell and Katz, Janicek and Katz, Geertsma, Firoozabadi and Katz, Pascal and Kingston, Norman Jones, Ruth and Ma, Liu, Ganesh, Coles and Hartman, Thauvin and Mohanty, Reid, Saskia and Jacques, Cooper, Fourar and Lenormand, Li , Yu Shu Wu , Olson, Barree, Friedel and Voigt, Khaniaminjan and Goudarzi, Macini, Xiaoyan, Yang to understand this non-Darcy flow coefficient in different types of formations particularly natural porous medium, fractured reservoirs, consolidated and unconsolidated formations 4-10. It has been carefully observed from their studies that this non-Darcy coefficient/beta factor can be related with the rock properties like porosity, permeability, tortuosity, and specific surface area, grain and pore size.

The present paper has three fold objectives:

- Thorough Literature Review of the existing Non- Darcy Correlations for Porous Media. (All the theoretical and empirical correlations for quantifying non-Darcy coefficient i.e., Beta Factor (β) have been carefully reviewed, presented and discussed in detail.)
- To prepare an algorithm for the determination of beta factor by using selected correlations taking permeability, porosity and tortuosity as input parameters.
- To convert and code the algorithm in to a robust simulator which can compute the beta values for a given set of data. To check the robustness of this simulator, it is validated and verified by a test/synthetic data obtained from the available open-source.

This study presents an understanding of non-Darcy flow behavior in porous formations (natural or fractured) and discuss all the non-Darcy flow correlations available in the literature. An algorithm and a user-friendly simulator has been presented to determine the beta values for a large input data

Darcy and Non-Darcy Flow Correlations

In most of the formations, the flow pattern is governed by Darcy's law which describes the linear relationship between pressure gradient and velocity. Darcy's law is inapplicable or inadequate in the case if the flow rate is significantly high which is usually near the well bore conditions. This Law is adequate to describe the flow of fluid and pressure drop at low Reynolds number *($Re < 1$)*. A uni- directional

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